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SIMILITUDE IN HYDRODYNAMIC TESTS INVOLVING PLANING

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Tests of small models of hulls are of major importance. Indeed, empiricism can be considered to be almost the only guide for the hull designer and, on the other hand, tests in full size can be considered only as altogether exceptional because of the difficulties they involve and above all because of the capital risk involved.

Shipbuilders have understood the importance of this for a long time and since the end of the nineteenth century many towing tanks have been built (the Glasgow tank, in 1882).

The methods of testing followed on these towing tanks seem practically perfect, especially in connection with the prediction of the maximum speeds of full-size ships. In fact, in the case of a series of vessels of the same construction, although the measured maximum speeds in full size showed differences of 6 percent, the figure deduced from the tank tests lay near the mean of these speeds. Unfortunately, as we shall see later, these methods are poorly suited to the case of high-speed hulls operating as planing craft: hulls of speedboats, hulls and floats of seaplanes. This circumstance may explain in part the lack of enthusiasm - in France, especially - that the method of testing small models has met with among seaplane people.

The resistance to forward motion of a partially immersed hull may be considered, as a first approximation, to be made up of a resistance of impact (form resistance) and a viscous resistance (friction and eddies).

The impact resistance manifests itself by the formation at low speeds of a bow wave forward and a hollow at the stern; at high speeds by the formation of two systems of waves: the diverging waves and the transverse waves. This resistance is the sum of the components, parallel to the direction of motion, of the normal pressures on the hull.

If one passes from the model to a hull of linear di-
mensions n times greater, the speeds are connected by
the law of mechanical similitude:

$$\frac{V^2}{L} = \text{constant}$$

L = some linear dimension

The normal forces given by the hydrodynamic equations (per-
fect fluid) also follow the law of dynamic similitude
(Reech's method) and are multiplied by n^3 .

The viscous resistance manifests itself by the forma-
tion along the surface of the hull of a layer disturbed by
the friction (laminar layer forward, then turbulent layer);
this layer is extended at the stern by eddies.

Unfortunately, the criterion for similitude of the
phenomena of viscosity is no longer the law of mechanical
similitude, but the Reynolds criterion:

$$\frac{VL}{\nu} = \text{constant}$$

Under these conditions the method used in ship tests
to convert from the resistance of the model to the resist-
ance of the full size is as follows: The total resistance
of the model is reduced by the resistance of friction,
this latter being computed for the wetted surface by means
of an empirical formula for friction. The remainder is
considered as the form resistance (wave-making resistance)
of the model. When multiplied by n^3 (law of mechanical
similitude) it gives the wave-making resistance of the
full size. The total full-size resistance is finally ob-
tained by adding to this wave-making resistance the full-
size frictional resistance computed by means of a formula
analogous to the preceding.

This method thus assumes that the phenomena of waves
and of viscosity are independent of one another; the accu-
racy of the results depends on the formulas used for fric-
tion. These formulas are based on tests made in the tank
on submerged plates (tests by Froude, tests by Gebers).

The correction for frictional resistance just described
is, as we have said, difficult of application to high-speed
hulls, and in particular, to the hulls and floats of sea-

planes. The wetted surface of this type of hull varies
rapidly with the speed; furthermore, it is difficult to
determine it with precision at the high speeds of planing.
Finally, also, at high speeds, friction appears not only
as part of the total resistance but also as the exciter of
a pitching moment that causes the trim angle of the hull
to vary with the scale. This change of trim in turn acts
on the system of waves and the mechanical similitude of
the wave-making resistance is disturbed. (It is the rec-
ognition of this fact that has led us at the hydrodynamic
laboratory at Saint-Cyr to test hull models at fixed trims,
measuring the resistance and the trimming moment.)

The Hamburg tank has made two series of comparative
tests on this subject, the results of which are particu-
larly conclusive. The first series (reference 1) was on
four geometrically similar floats that had respectively,
the following lengths: 3.90 m, 2 m, 1 m, 0.50 m (12.79 ft.,
6.56 ft., 3.28 ft., 1.64 ft.).

The four curves of resistance, expressed as kilograms
per ton of displacement (mechanical similitude), as a
function of speed, are given in full lines on figure 1.
It will be seen from these curves that the maximum resist-
ance varies from 293 kg for the 3.90 m float to 362 kg for
the 0.50 m float; at a speed of 10 m/s, the resistance of
these same floats varies from 184 kg to 287 kg, or differ-
ences of 23 percent and 56 percent, respectively.

The second series of tests (reference 2) was on five
models of hulls having the following ratios to the full
size: 1/1, 1/3, 1/6, 1/9, 1/12. The characteristic
curves, also expressed in kilograms per ton, are shown in
full lines on figure 2. If one excludes the full-size
model for which the maximum resistance was not reached on
the tests, one finds, nevertheless, that the maximum re-
sistance is 218 kg for the 1/3 size model and 253 kg for
the 1/12 size; at a speed of 13 m/s the resistance varies
from 125 kg to 177 kg. The differences are thus 16 percent
and 42 percent, respectively, for models of which the ratio
of the dimensions is 4.

From these tests it is plain that the correction for
mechanical similitude, the only one that thus far appears
to have been applied abroad in connection with tests of

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kg X 2.20462 = lb.   m/s X 3.28083 = ft./sec.

seaplane hulls, is entirely inadequate, especially at speeds
greater than that corresponding to the maximum resistance.
In this manner we have been led to the thought that the vis-
cous resistance - considered, until very recently, as negli-
gible at high speeds - might on the contrary be preponderant
at those speeds.

Accordingly, we have been led to the following approxi-
mate method of correction: We divide the characteristic re-
sistance speed curve given by the model tests into two
parts: the ascending branch, corresponding to speeds lower
than that of the maximum resistance, and the branch corre-
sponding to speeds higher than that of the maximum resist-
ance. We assume that the first branch corresponds solely
to wave-making resistance, friction being negligible. By
this hypothesis, the first branch can be converted from
model scale to full size by the simple application of the
law of mechanical similitude.

For the second branch, we assume that the resistance
can be considered wholly as frictional resistance and that
it follows the particular law of similitude given by Gebers'
formula for frictional resistance:

$$R = 0.0103 \; l^{-0.125} \; V^{1.875} \; \frac{\gamma}{g} \; \nu^{0.125} \; S$$

in which,

R   is the frictional resistance

l , the wetted length

V , the speed

S , the wetted surface

For a model having a linear scale of l/n, this formula
becomes:

$$R_m = 0.0103 \; \left(\frac{l}{n}\right)^{-0.125} \; \left(\frac{V}{\sqrt{n}}\right)^{1.875} \; \frac{\gamma}{g} \; \nu^{0.125} \; \frac{S}{n^2}$$

(the speed following the law of mechanical similitude
$\frac{V^2}{L}$ = constant).

To convert to scale size, it therefore is sufficient
to multiply the ordinates of the second branch by the coef-

ficient $\dfrac{R}{R_m} = n^{2.8125}$.

If the second branch has already been converted to the full size according to the law of mechanical similitude, or - what is the same thing - if the resistance is expressed in kilograms per ton, the foregoing coefficient will become:

$$\frac{n^{2.8125}}{n^3} = \frac{1}{n^{0.1875}}$$

Finally, if the passage of the hull from the first regime (immersed) to the second (planing) is definite, a first approximation to the maximum of the curve at full size can be given by extrapolating the second branch of the curve converted at $n^{2.8125}$ up to the first branch converted at n^3.
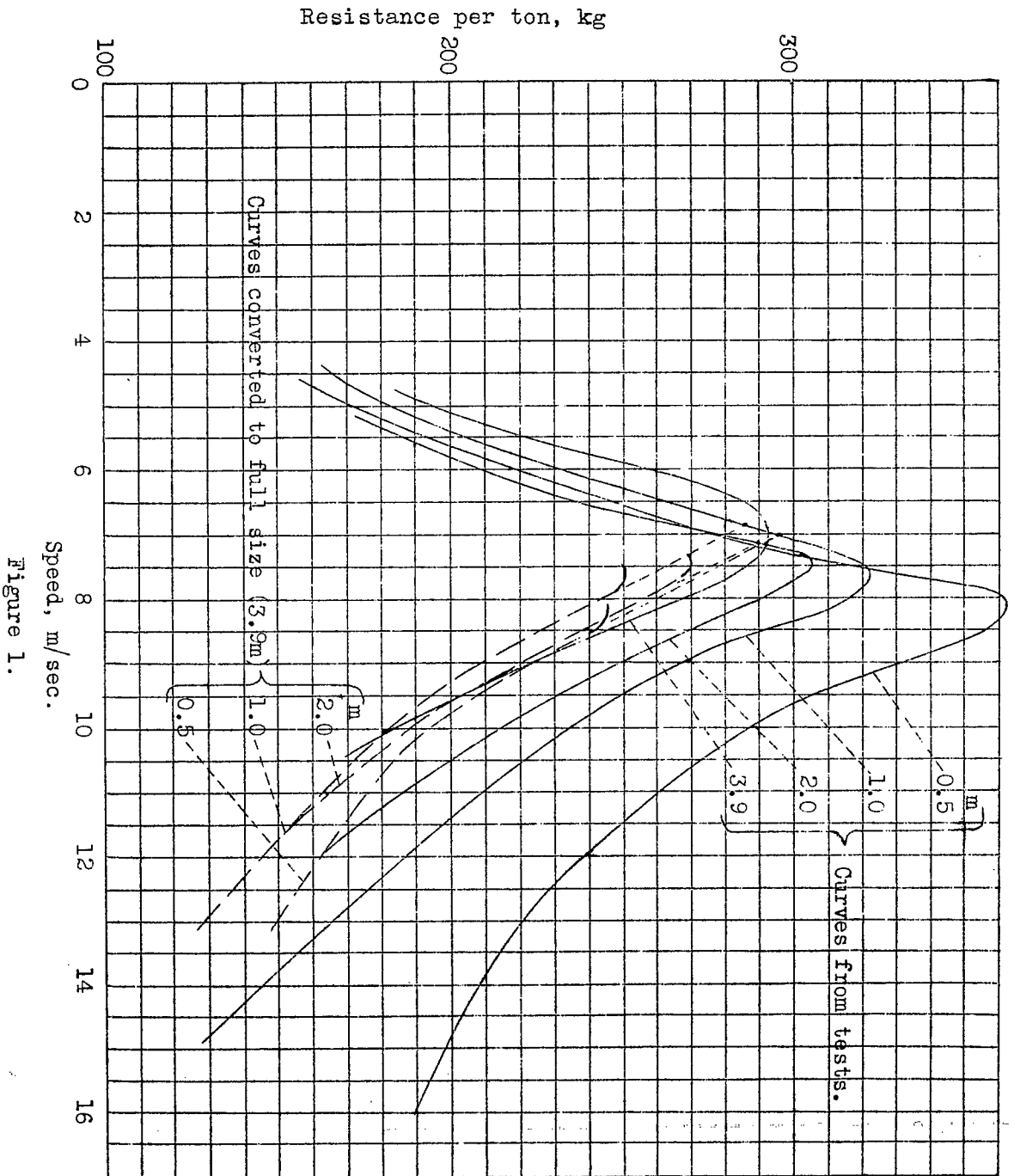
The method just described has been applied in figures 1 and 2 to the curves published by the Hamburg tank. It can be seen in these figures that the widespread sheaf of experimental curves is, by this method, condensed about the curve corresponding to the full size; it can also be seen in figure 1 that the maximum of the full-size curve may be approximated, by this method, with very good accuracy.

Accepting the crudeness of the hypothesis, we believe that such a method of conversion should be considered only as a method of first approximation that may be used provisionally until the laws of planing surfaces are established physically. We wish to present the method only in that light.

Translation by Starr Truscott,
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for Aeronautics.

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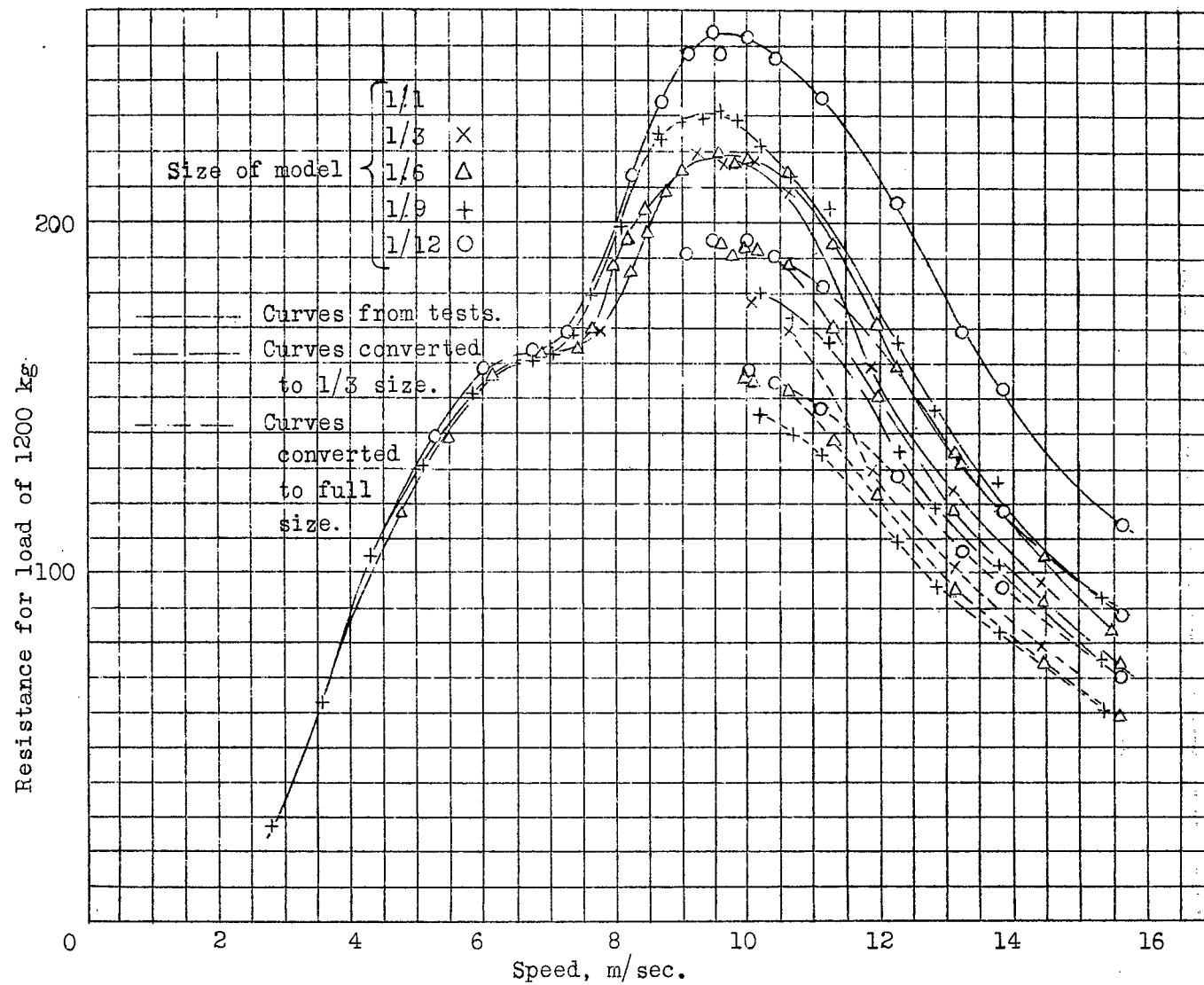   Investigations.   T.M. No. 704, N.A.C.A., 1933.

Resistance per ton, kg

Speed, m/sec.

Figure 1.

Curves converted to full size (3.9m)

Curves from tests.

Size of model {
1/1
1/3 ×
1/6 △
1/9 +
1/12 ○
}

————— Curves from tests.
—·—·— Curves converted to 1/3 size.
—··—··— Curves converted to full size.

200

100

Resistance for load of 1200 kg.

Speed, m/ sec.

0   2   4   6   8   10   12   14   16

Figure 2.

Fig. 2